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Working with Litz Wire

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Litz Wire from the German “Litzendraht” – Litz for “strands” of wire and Draht – for “wire”, is a special type of electrical conductor that consists of multiple strands of individually insulated wires that allow the flow of high frequency alternating electrical current without appreciable loss because of electrical resistance or impedance in the conductors.

The problem when using commercially available Litz Wire, for harness assembly, is how to efficiently terminate it. Litz Wire is now being used in electrical harnesses for interconnections to flat screen TVs, in microwave ovens, for speaker connection cables, electric vehicle charging systems, communications equipment, etc.

Litz Wire

When using alternating current, a phenomenon occurs at elevated frequencies that force the outer surface or skin of the wire to carry most of the electrical current. This phenomenon, called the Skin Effect, increases in intensity, and forces the electrical current even closer to the surface of the wire as the frequency increases. To avoid the detrimental effect of this phenomenon, Litz Wire is used.

Litz Wire has many individually insulated conductors, sometimes into the thousands. The reason it is used is that the individual Litz Wire strand’s diameters are very small, and its radius will be about the same or less than the depth of Skin Effect conduction. By bundling many individually insulated small wires together, the end result of the Skin Effect can be negated. If Litz Wire is not used, and large diameter wires are

Examples of Terminated Litz Wire Bundles

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substituted, excess wire material will be wasted, as the inside of larger diameter wire serves no purpose. Also, by using larger wasteful conductors, much more room will be required for the wire than when using Litz Wire.

There are other methods that can be used to eliminate the results of the Skin Effect, such as using hollow tubing or clad metals, instead of solid large diameter Copper conductors, or Litz Wire

Non-Litz Wire Terminations

Stranded wire, where the individual strands are not insulated is used instead of a single solid wire because it is flexible and can be bent around obstructions and inserted into tight areas. Litz Wire is similar to normal stranded wire, but each individual strand is insulated from its neighboring strand. Litz Wire is usually made of fine (small diameter) strands, as their size is designed to accommodate the surface depth of required electrical conduction because of the Skin Effect phenomenon.

There are times that bundles of individually insulated larger wires are used for low frequency applications, such as in the manufacture of electric motors, transformers, etc. These bundles of wire are not Litz Wire, but individually insulated stranded groups of wire, as they are not affected by the Skin Effect phenomenon.

If say, you are winding an electric motor's stator with a large diameter wire or placing heavy cable into the lamination of a transformer, it would be pretty hard to bend the wires and get them into place. If only one conductor is used, it might not even be possible to bend the wire around the sta-

Examples of Terminated Non-Litz Wire Bundles tor's laminations or feed them through and around obstacles in the transformer's laminations. However, you can substitute many individually insulated smaller diameter wires for one large insulated solid conductor. These many wires can be bent and angled much more easily than a single large diameter wire.

The use of multiple strands of insulated wire to solve the physical problem of inflexible large wires, in building motors, transformers or other inductive devices, is similar to using Litz Wire to solve the Skin Effect problem for high frequency applications. Both problems can be corrected by using multiple smaller diameter insulated wires in a bundle. However, the non-Litz Wire bundles are used to solve a physical problem, while Litz Wire is used to solve an electrical problem. Using either type of wire (Litz or non-Litz bundles) creates the same termination problem.

Skin Effect

The Skin Effect is a phenomenon where electrical alternating current (AC) is forced to the surface of an electrical conductor (wire) as the frequency of the AC current flowing through the conductor increases. The higher the frequency, the shallower will be the depth from the outer surface of the wire, in which the current will flow. Therefore, the Skin Effect causes the resistance of the conductor to increase, above the Direct Current (zero Hertz) measured resistance, as the frequency increases, and depth from the surface of the conductor where the current will flow, decreases. This phenomenon occurs as the current flow moves away from the strongest magnetic field area of the conductor, which is towards its center. As the full amount of metal in the conductor is not being used for current flow, the actual current flow will heat the limited area where it is being conducted, and therefore, increases its resistance, as it gets hotter and hotter, and could possibly over-heat the conductor. Remember, as a metal heats, its resistance increases. If it continues to heat, its resistance continues to rise, and a vicious cycle occurs, until the metal melts.

When a metal conductor is used to carry AC current, a separate alternating magnetic field is created around the conducting metals. The alternating magnetic field results in a separate reverse voltage that is induced within the metal's conductor (in addition to the electrical energy of the alternating current that normally flows through the conductor), and then generates its own counter current counter flow in the conductors. This counter current flow is the primary reason for the Skin Effect phenomenon, which forces the electrical current to the outer surfaces of the metal's conductor. The higher the AC frequency, the closer to the conductor's surface the electrical current is pushed. The center area of the electrical conductor, therefore, does not conduct any real amount of current. However, this center area of the conductor can absorb heat generated by electrical resistance from the outer current carrying area of the conductor.

Using large diameter conductors at a high frequency serves no purpose. A really large diameter single conductor might be more efficient because the outer surface area of the conductor (circumference times its length) is larger than the diameter of a smaller conductor's outer conductor surface area. However, the center of the conductor serves very little real purpose other than as a conductor of heat away from the surface where current is actually flowing.

Multiple small wires can also be used to conduct high frequency current, as long as the wires are individually insulated from each other, and in close proximity. Uninsulated strands of wire that are bunched together cannot be used as they will touch each other, and act as one large conductor. By using many small individually insulated conductors, in multiples with as large as a few thousand strands, large amounts of very high frequency current can be passed through these multiple conductors without appreciable loss.

In very high frequency applications, hollow tubing is, at times, used, as the center portion of the conductor does not have a real function. This hollow area can also act as a conduit for cooling fluids to remove any resistive heat. As an example, very large diameter thin wall tubes are used as conductors in radio transmitters. Fluids pumped through the tube are used to cool the conductors.

Copper-clad materials (not plated), such as Copper-clad steel and Copper-clad aluminum can also be used, instead of solid Copper for conducting high frequency current. These bimetallic wires are cost effective, as they eliminate a large portion of the expensive Copper metal. Also, when using Copper-clad steel wire, the physical strength of the wire is much greater than when using 100% Copper wire. Copper-clad wires are used for electrical transmission lines and feed lines for radio/TV transmitters and antenna, as they are self supporting.

Proximity Effect

Another phenomenon that relates to conductors of high frequency current is the Proximity Effect. Rather than go into details concerning this phenomenon, let's just understand that to eliminate its detrimental effect on the conductor, the strands of Litz Wire must be held in very close proximity and are normally twisted or braided, so that the individual strand currents are as physically equal as possible.

Litz Wire Construction

As each individual strand of Litz Wire is insulated, this insulation must be completely removed in the termination area for a valid termination to occur. Also, after the insulation is removed, all non-insulated portions of the wire strands must then be held together so they become a common single strand where terminated.

Each individual strand of Litz Wire is coated with enamel type magnet wire (aka winding wire) film insulation, or occasionally a fiber type served (wrapped around) insulation. Fiber insulation, as well as various other types of organic insulations can also be used to enclose the outer bundle of Litz Wire, to avoid Proximity Effect problems. For many applications, silk threads are used to hold the bundles together. These insulations are available in various types that have specific thermal maximum operating temperatures. Below is a list of some, but not all, of these insulations:

Fiber Insulations	Temperature Class
Silk	Not Rated
Cotton	105° C
Nylon	130° C
Dacron	155° C
Nomex	250° C

Glass	260° C

Film Insulations	Temperature Class
Polyvinyl Formal	105° C
Polyurethane	155° C
Polyester-imide	180° C
Ployester-amide-imide	200° C
Polyimide	240° C

Litz Wire Termination

As Litz Wire is made of many individually insulated wires, it is difficult to terminate bundles of this wire, unless all of the insulation in the termination area is first removed. Under normal circumstances, not more than three conductors of film insulated wire can be terminated by using crimp terminals. The reason is that the teeth in the crimp terminal will not be able to make contact each and every time with more than three of the wires. It's possible that four wires could make contact, at times, but in a production atmosphere this could not be guaranteed. At times, hundreds or thousands of individually insulated strands of wire are contained in a Litz Wire bundle.

If the film insulation can be removed in some way, without damaging the integrity of the wire, the wires could be soldered, brazed, crimped, or welded together or to a terminal. However, removing this insulation is not easy without damaging the wire's physical structure. Until recently, low temperature film insulation was used, which could be removed by dipping the insulated wire bundle into molten solder which would burn the insulation off. However, the trend, recently, has been to use high temperature film insulation in the range of Class F (155° C) or Class H (from 180° C to 220° C), which molten solder cannot break through. Crimp terminals cannot make a satisfactory connection, because the terminal's insulation piercing teeth cannot reach every strand in the Litz Wire bundle. Another method is to use fused salts to chemically dissolve the organic film insulation. This does not work well, in production, as the chemical residue from the salts cannot be completely removed from inside the Litz Wire bundle, after the insulation is dissolved.

Non-Litz Wire bundle strands, can be abrasively cleaned, strand by strand, if the strands are large enough in diameter, so that they will not be physically damaged during cleaning. Abrasive removal will not work for Litz Wire as the strands normally are too small. Removing the insulation strand by strand is a labor intensive and time consuming process that is really not productive.

The only proven successful production method to terminate large bundles of insulated wire is Tube Fusing, using the SN-Fusing process. A terminal or tube is used and all of the film insulated on each and every wire strand is removed. Any outer coating insulation (holding the wire strands together) can also be removed during Tube Fusing, if required.

What is Fusing?

The general term "Fusing" is a method of joining low resistance metals with a type of machine similar to a resistance welding machine, but without appreciable distortion or damage to the parts being joined. Normally, when Copper is resistance welded (aka spot welding, butt welding, projection welding, etc.), it is drastically distorted, to a point where some of the metal looses its physical integrity. This does not occur with fusing.

There are two different methods of joining metals that use the word Fusing, “Commutator or Tang Fusing”, or a totally different method called “SN-Fusing”. What actually happens in commutator/tang fusing (which is not the same as the SN-Fusing process), is that the parts are heated, cleaned, softened and pushed together until all the air between them is eliminated, and the high points of one metal part are pushed into the low points of the other, and vice versa. A surface adhesion contact will then hold the parts together, which is a physical connection. With SN-Fusing, a diffusion metallurgical bond is developed.

As the strength of the Fused (not SN-Fused) joint is not too secure, it must be used only with parts, such as a tang terminal or a wire slotted commutator structure, that are specifically designed to be fused. The commutator or most tang terminals are not designed to handle the high temperatures required in the SN-Fusing process.

SN - Tin

Tin (SN-Stannum) is a natural element that is a silver white metal with a bluish tinge. It is not oxidized on exposure to air at normal ambient temperatures. Tin is used mainly to coat metals, such as iron, steel and Copper, to protect them from oxidation, as well as being an ingredient in soft solder. Pure Tin causes no harm to humans. It is, therefore, used as the main ingredient in pewter, which is made into eating utensils for humans, as well as the inside coating for some metal food containers and cooking utensils. Tin has a low coefficient of friction, and therefore, is sometimes used in bearings.
Below is a listing of some of Tin’s characteristics and specifications:

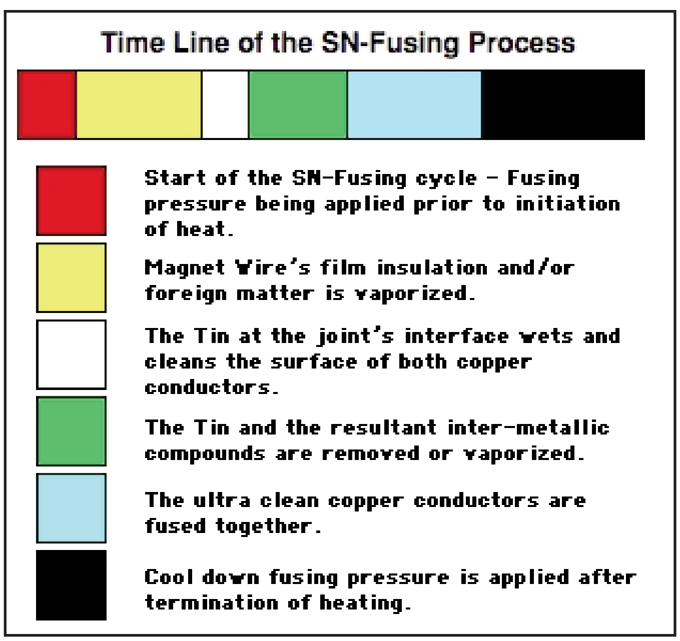
- Atomic Symbol - SN
- Atomic Number - 50
- Atomic Weight - 118.70
- Melting Point - 231.9°C (449.4°F)
- Boiling Point - 2.270°C (4,180°F)
- Tensile Strength - (20°C) 1.52 KG/MM2 (2,161.94 PSI)
- Shear Strength - (20°C) 1.26 KG/MM2 (1,792.14 PSI)
- Commercially Pure Tin - 99.85%

Tin acts as a solvent of Copper. If Tin is heated until it is liquid, and a bar of Copper is inserted into the molten liquid Tin, the Copper bar would eventually dissolve. This solvent action, called wetting, is what allows Tin to coat Copper by dissolving its surface molecules. Tin adheres or wets to Copper’s surface with a strength comparable to that which a piece of solid metal holds itself together, that is, by the attraction between adjacent atoms which are generally termed chemical forces. Tin being attached by such forces, cannot be mechanically pried off the Copper’s surface. Further, Tin cannot be completely drained off or wiped off when molten or liquid, for the Copper’s surface remains permanently wetted by a film of it.

A Copper/Tin inter-metallic compound is formed whenever Tin wets Copper. This compound itself is not strong or advantageous. Therefore, by using a minimum amount of Tin which is brought into contact with the base Copper alloy, for as short a time as possible, we can “Tin”, wet or coat the Copper, while keeping the Copper’s basic strengths and properties. For tinning to occur, the Copper must be relatively clean of any foreign matter. Without the wetting of the Copper by the Tin, there is no tinning action, possibly only a mechanical anchorage at surface irregularities. Tin's interface with Copper is chemical in character rather than purely physical, as it involves a non-mechanical or metal solvent action.

The Copper/Tin inter-metallic compound that is formed when Tin wets Copper is called bronze. However, the alloy produced when Tin wets Copper is Copper rich. Bronze, traditionally, consisted of less than 8% Tin. The Copper/Tin inter-metallic compound that results from the wetting action of the Tin, has more than 8% Tin with the balance being Copper. This compound approximates the strength of Tin, and has none of the physical qualities of bronze.

Tin can also be applied to Copper by electroplating or chemical plating in an alkaline sodium stannate solution or acidic stannous sulfate solution. This electro chemical tinning can be performed where dipping an article into molten Tin would heat damage it, or a pre-determined coating thickness is required. Electroplating of Tin on Copper, is covered by (U.S.) Military Specification: MIL-T-10727A. Coating thickness is normally from 0.0001 to 0.0006 inch (0.00254 MM to 0.01524 MM).



SN - Fusing

SN-Fusing consists of six basic steps. These steps are carried out automatically, usually in less than one second, during the SN-Fusing process. At least one of the parts being fused using the SN-Fusing process must be coated with Tin.

1 - Fusing pressure is applied to the parts that are being joined, until a preset level of pressure is reached. At this point, heating is initiated.

2 - Heat is applied to the fusing electrode(s), and then dissipated into the parts being fused.

3 - As heat in the parts being fused increases, first the magnet wire's film insulation, if any, is vaporized.

4 - Then the Tin, which is at its molten point, acts as a solvent to clean the surface of the Copper conductors.

5 - As the dissipated heat increases, the Tin and any inter-metallic compounds are vaporized and/or driven from the joint's interface.

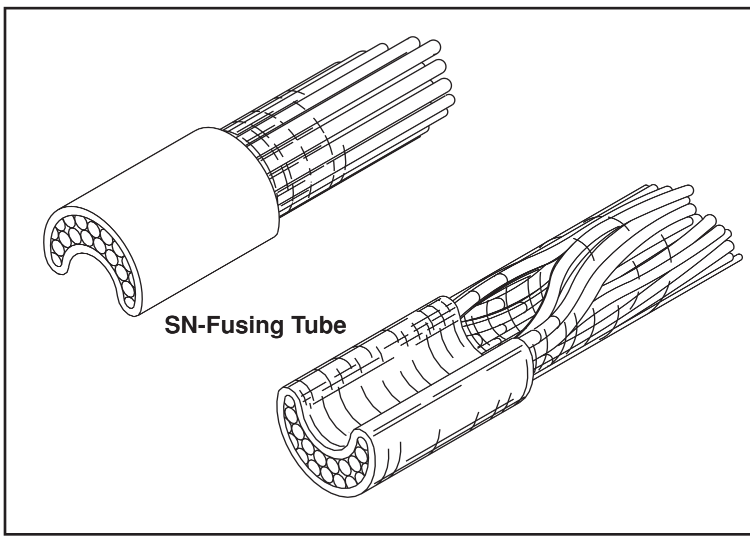
6 - The resultant ultra-pure Copper at the interface of the parts is then fused, resulting in a diffusion bond. However, the fusing pressure must be continually applied, until the joint cools to a reasonable temperature, or the plastic metals will break apart, because of the contractual forces that are being applied to them during cooling.

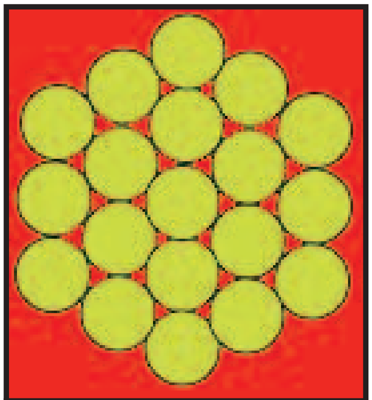
The Tin allows the conductors at the joint's interface to be ultra-clean. Because there is no foreign matter or gases at the interface, there is a mingling of molecules. In actuality, this is a diffusion of vacancies where voids are filled with matter that are in their plastic state. If the conductors at the joint's interface are not ultra-clean, a type of fused connection will occur, but there will not be a true diffusion bond. Instead, there will be a surface adhesion effect, which is similar to what is described in the above section on "What is Fusing?". When using Tin in a joint, enough heat must be applied to remove the Tin and any inter-metallic compounds, otherwise, the joint will be adulterated and a diffusion bond will not take place.


Bare Stranded Wire Terminated to Multi Magnet Wire Strands for an Induction Motor Using a Very Inexpensive Tube Terminal

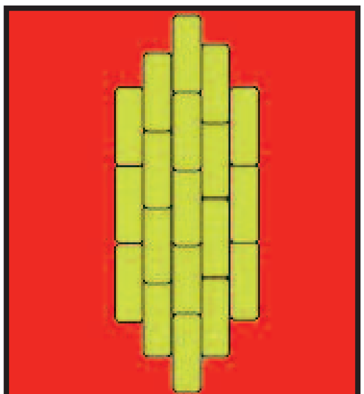
At least, commercially pure Tin must be applied to one of the conductors, or the terminal. With SN-Fusing of Litz Wire, the tin is applied to the tube terminal. The minimum thickness of the Tin on the terminal should be approximately 0.0002" inch (0.00508 MM) for Copper and 0.0005" inch (0.012 MM) for copper rich brass. No more than a 0.004" (0.1016 MM) coating should be added. If too thick a coating of Tin is applied, too much Copper will have to be converted to inter-metallic compounds and too much heat will be required to force the Tin and these compounds from the joint area. The heat being applied to the joint is used to remove any insulation, foreign matter, Tin and inter-metallic compounds, not to melt the Copper parts being joined. If we could fuse two conductors that had no insulation and an ultra-clean interface, without requiring any pre-cleaning, we would use a relatively low level of heat to accomplish this. The high levels of heat are required, when cleaning is performed during the SN-Fusing process.

We have been talking about Tin (SN - Stannum) - pure Tin. The SN-Fusing process must use pure Tin, at least at the 99.84% level of commercially pure Tin, not solder or any other Tin alloys. Any Lead metal added to the Tin will retard the cleaning effect, and introduce environmental and health problems. As we vaporize the





ROUND WIRE, WITH SPACE BETWEEN EACH WIRE, THUS MAKING POINT TO POINT CONTACT BETWEEN EACH WIRE.



FLATTENED ROUND WIRE, THUS MAKING CONTACT IN MORE PLACES THAN ROUND WIRE.

Tin and intermetallic compounds, particles can be suspended in the air. Commercially pure Tin and Tin/Copper intermetallic compounds are not hazardous. However, Lead (metal), and its fumes or particles would have to be controlled, as they are dangerous.

SILVER AND GOLD FUSING

There are other metals, Silver (Ag), and Gold (Au) which have properties that are similar to Tin with regard to its solvent action against Copper, and are sometimes used to plate or coat Copper for fusing.

Silver has a higher melting point, is not as aggressive a solvent as Tin, but will practically serve the same purpose. Silver costs about as much per Troy ounce (1 Troy ounce = 31.1034768 grams) as Tin costs per pound (1 pound = 453.597 grams). Silver would be used instead of Tin only when the wire must be used in a high temperature environment.

Gold (Au) also is a solvent of Copper, but is not normally used as a coating for Copper that will be fused, because of its extremely high cost.

SN-FUSING APPLICATIONS

The SN-Fusing process replaces many known electrical conductor joining methods used today. It always produces a valid joint at a lower cost, when compared with the processes it replaces. It can be used for producing Copper magnet wire connections in place of soldering, terminal crimping or terminal displacement. This is ideal when terminating Litz Wire that is made with high temperature magnet wire film insulation, as the SN-Fusing method removes the film insulation during the wire termination process.

TUBE-FUSING

When many (theoretically unlimited) individual magnet wire leads, or Litz Wire, by themselves, must be joined together or to stranded or solid wire, a tinned tube can be used. The tube acts as a gathering device, as well as a mechanical terminal. The wires are placed into a tinned Copper tube. Fusing electrodes then engulf the tube and it is fused.

The advantage of the tube is that the Tin, inside the tube, cannot easily be removed from the joint area, during heating, as the tube holds it in place. Therefore, the Tin tends to wet all or most of the wires inside the tube before it is driven out of the joint. This means that most, if not all, of the conductors inside the tube, will be cleaned by the Tin. Another advantage of the tube is that it acts as a mechanical terminal. The wires are gathered and trapped inside the

Tube Terminated Bundled Magnet Wire Brazed to a Brass Threaded Bolt. This assembly is used as a pass through terminal on a traction motor's housing.

The SN-Fusing machinery produces enough heat when removing Class F or H magnet wire insulation, during the fusing process, to flow the brazing alloy

Please note the blackened color of the Copper Tube. This occurred because of the fumes from the heated brazing alloy, which are not detrimental to the wire's termination.

tube.

The tube is usually made from Copper tubing that is cut to length and deburred at the internal circumference ends. Tube diameters are available from an internal diameter of less than 0.125 inch (3.1 MM) to more than 2.0 inches (50.8 MM). The tube, of course, must be either coated or electro-plated with Tin. A sealed tube that includes a flag, or a large crimp type terminal that has a tube shaped bore can also be used. Provision for a pressure relief orifice must be included in this terminal design, so that any gases created during fusing can be removed from the inside of the terminal. If the tube is made from flat stock that is rolled into the tube shape and brazed, special tooling must be used for fusing, but it can be fused.

Two types of Tube-Fusing machines are available. One is a bench type machine where the work being fused is brought to the machine. The other is a fusing gun type machine where the machine is brought to the work being fused. The Tube-Fusing system is designed to terminate from small size connections to extremely large connections. Automatic tube feeding systems are available for presenting the tubes to fusing electrodes. These systems speed up the joining process, as the tubes do not have to be manually handled.

As each strand of Litz Wire is normally made of round wire, the wires, if held tightly together, will make point to point contact and will leave air gaps between themselves. This means that there will be high resistance contact between the individual strands. The ideal is to compress the strands until they flatten against each other so that they make large intimate contact and eliminate just about all of the air between them. We also want to anneal or stress relieve these now compressed strands, so that they do not attempt to return to their previous round shape. Both of these requirements are achieved when SN-Fusing of Litz Wire or magnet wire bundles in tinned tubes, because of the high heat used during the process.

The quality of the SN-Fused connection is excellent. Mechanically, the wires are held in place and cannot normally be pulled out of the fused tube. With fine strands, such as Litz Wire, the individual strands will stretch and break outside of the tube area, when pulled. For bundles of very large diameter wires, it might be possible to pull individual wires out of the tube, but hundreds of pounds (45.5 KG equals about 100 pounds) of force would have to be applied.

Electrically, the fused connection between individual strands and other strands, as well as the tube, have an extremely low electrical resistance. As an example, a recent production study found that a bundle of 76 wires, 1.06 mm each in diameter wires (about number 18 AWG), have had their strand to strand and strand to tube electrical resistance measured at less than half of a Micro-Ohm. Practically, this means that the termination's electrical resistance is just about nil. It has been shown in production studies that the resistance of an SN-Fusing termination is equal to a solder or brazed joint, but without the problems incurred in making such a joint.

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SN-Fusing is a method of easily, inexpensively and reliably terminating Litz Wire in production. The resultant termination creates an electrical connection that is not available by using any other wire joining process.

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